Enhanced Predictability Through Lagrangian Observations and Analysis

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LONG-TERM GOALS

This effort is closely linked with our effort on ONR grant N00014-00-1-0019. We are motivated to develop strategies for the deployment of drifting sensor arrays that maximize the amount of environmental information collected with the fewest sensors. Two critical concerns are: maintaining array position inside a region of interest, and minimizing array distortion during the deployment. Our primary long-term research goal is to quantify submesoscale stirring process. Calculating the origin and fate of particles is an essential part of our analysis. A better understanding of submesoscale stirring will contribute to improved drifter array deployment strategies.

OBJECTIVES

Three objectives were pursued during this performance period:

- Transition Lagrangian analysis codes to a domain-independent Fortran 95 form which allows for domain and array size definition at run time.
- Develop code for automatically locating stagnation points.
- Develop code for computing relative dispersion from trajectories initialized at each point on a model grid.

APPROACH

As documented in publications and previous progress reports, we have developed a variety of Lagrangian methods to quantify advective processes from synoptic velocity maps. We have applied these methods to both observed velocity fields obtained by HF radar, and model velocity archives. For the latter we focus on data-assimilating models. To date we have not used statistical methods to parameterize subgrid scale processes, so that our computed trajectories describe only simple advection of passive particles. These methods have provided new insight into submesoscale processes.

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Our Lagrangian tools include the following:

Inflowing/outflowing manifolds – Using archived two-dimensional velocities and careful initialization of particles, precise curves that define manifolds can be numerically computed in both forward and backward time. In the vicinity of hyperbolic points (always associated with nearby stagnation points), these manifolds define flow boundaries where strong deformation occurs. Because of their fundamental importance, it is highly desirable to automate manifold computation. Regrettably, the numerical challenges associated with an automated code remain daunting.

Gridded trajectories – To quickly understand the Lagrangian character of a two-dimensional velocity archive, regular grids of particle initial positions can be used to compute both forward and backward time trajectories. Maps of these trajectories give an impression of the evolving flow field, and the trajectories can be used to compute quantities like relative dispersion.

Relative dispersion – Using gridded trajectories computed from a two-dimensional velocity archive, relative dispersion in both forward and backward time can be computed. Regions of strong dispersion are closely related to the more precise manifold structure in hyperbolic regions.

Finite-scale Lyapunov exponents – Either finite-time or finite-length Lyapunov exponents can be estimated for a two-dimensional velocity archive. These are closely related to relative dispersion, and are more straightforward to compute than manifolds. Lyapunov exponent maps give a synoptic picture of local deformation in the same way that relative dispersion maps do.

Synoptic Lagrangian maps – For a defined region of interest, gridded trajectories computed from a two-dimensional velocity archive can be used to compute Lagrangian characteristics at each point on a regular grid. Synoptic maps of Lagrangian properties summarize the particle behavior over an entire domain. Maps can be computed for either forward or backward time quantities. We compute synoptic maps of residence time, particle source, and particle fate.

WORK COMPLETED

Tasks accomplished during this funding period include:

- Converted code for computing manifolds, gridded trajectories, and relative dispersion to a domain-independent Fortran 95 version which defines the domain and array sizes at runtime.

- Tested a simple automated routine for identifying candidate stagnation points in the Gulf of Mexico CUPOM model. Typically 500-600 candidate stagnation points are found at each time step, so tracking them over time remains a very challenging problem.

- Computed relative dispersion maps for the Gulf of Mexico to study the evolution of Loop Current Rings and multi-pole structures. We found that computed manifolds typically correlate well with regions of rapid relative dispersion.

- Completed preliminary manifold and relative dispersion calculations for the Gulf of Mexico HYCOM model, for comparison with our CUPOM results.

RESULTS

We are striving to automate as much of our Lagrangian analysis as possible. In order to automate the computation of inflowing/outflowing manifolds, candidate stagnation points (SPs) in regions of hyperbolic flow must be found. We implemented a simple automatic routine for finding candidate SPs in the Gulf of Mexico using two-dimensional velocity fields from the CUPOM model. Figure 1 shows an example map of candidate SPs for 11 October 1998, when a strong quadrapole existed in the southwestern gulf. There are 556 candidate stagnation points shown in Figure 1. The number and location of these candidate SPs changes rapidly over time periods of one day, so tracking them in time remains very challenging. We are now pursuing methods to stabilize the SP distribution to make tracking them easier to automate.

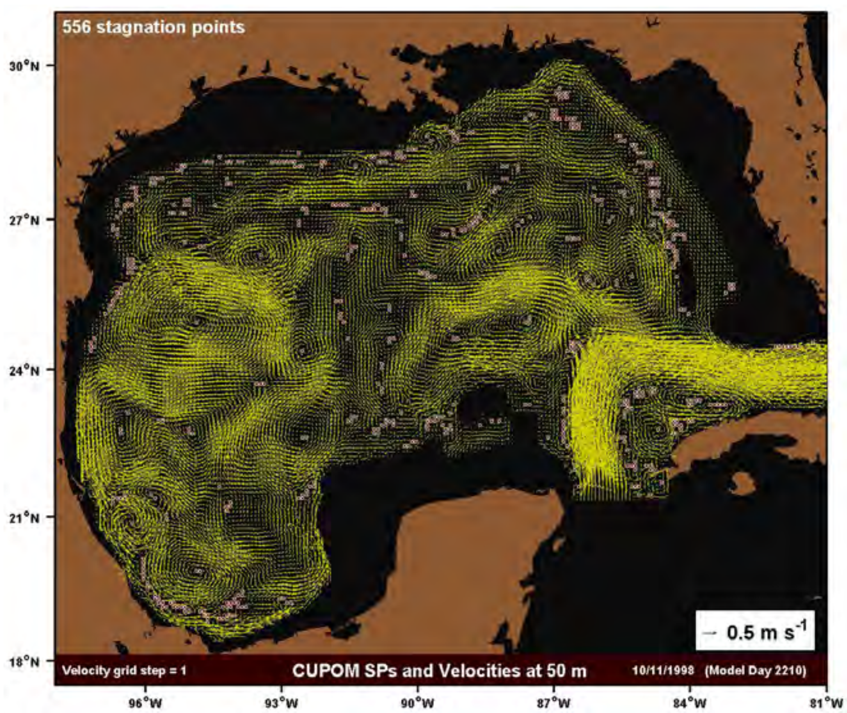

Figure 1: Example map showing stagnation points (red circles outlined in white) from a simple algorithm using CUPOM model velocities at 50m for 11 October 1998. The algorithm found 556 candidate stagnation points.

Since automated computation of manifolds remains challenging, we have investigated surrogates that are easier to compute. In FY07, we implemented a code for computing relative dispersion using forward and backward time trajectories initialized at every model grid point at a single depth. We have computed relative dispersion maps for the Gulf of Mexico using the CUPOM model and for the East Asia Seas using the EAS16 model. We found that, for the Gulf of Mexico, manifolds that we compute correlate well with regions of rapid dispersion. We expect, then, that relative dispersion maps will yield much of the information contained in manifold maps, which are more precise, but more difficult to compute. Figure 2 shows an example relative dispersion map for 11 October 1998 (compare with Figure 1). Red (blue) curves show regions of rapid forward (backward) time dispersion. For the strong quadrapole in the southwest, there is a well-defined, nearly-orthogonal intersection of red and blue curves which closely approximates a hyperbolic trajectory, which can be precisely located by manual initialization of a manifold computation. Figure 2 also shows the rich dispersion structure in Gulf of Mexico, which has a persistent, energetic mesoscale flow.

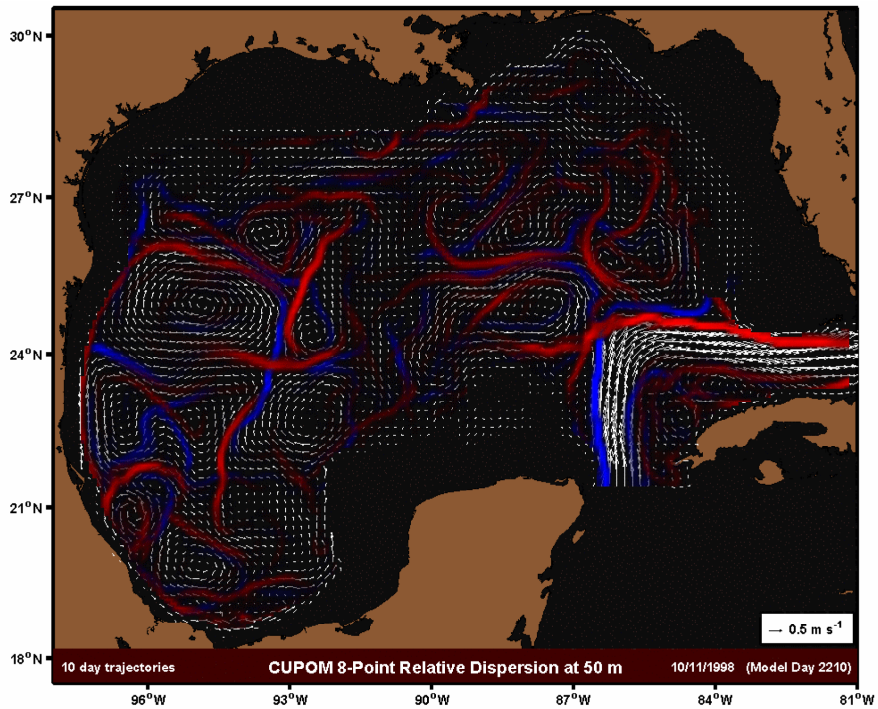

Figure 2: Example relative dispersion map for 11 October 1998 for the Gulf of Mexico based on 50m velocities from the CUPOM model. Forward (backward) time relative dispersion is shown in red (blue). Model velocities are shown as white vectors.

IMPACT/APPLICATIONS

The Gulf of Mexico continues to serve as a very useful test area for implementing and refining our Lagrangian analysis tools. The insights we have gained from our Gulf of Mexico analysis have been applied to our analysis of the Navy EAS16 model as part of our work on ONR grant N00014-00-1-0019. We are now focusing on refining our analysis products to support Navy acoustic array deployment planners.

RELATED PROJECTS

The research performed on this grant is closely related to ONR grant N00014-00-1-0019. That grant applies many of the techniques used in this study to velocity and hydrodynamic fields from a Navy data-assimilating model of the East Asia Seas area (EAS16). The PI and CO-PI of the present grant are also the principals on the latter grant.

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